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STUDIES OF AN ORBITAL GRADIOMETER MISSION

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Abstract

The goal of using an orbital gradiometer mission to provide an accurate (1-2 mgal), high resolution (1° by 1°), global map of the earth's geopotential is currently being investigated. This investigation involves the simulation of the satellite ephemeris and the corresponding gradiometer measurements which can be used in the study of various techniques and methodologies that have been proposed to recover the parameters used in modeling the geopotential. Also, the effects on the mission of various time varying forces acting on the spacecraft have been included in the studies.

Introduction

The goal of these studies is to create an accurate ephemeris and set of 'perfect' gradiometer measurements to study various techniques to recover the parameters of the geopotential model and to study the effects of various force model, ephemeris, and measurement uncertainties on the recovery of the geopotential parameters. This research effort began by assuming a Geopotential Research Mission (GRM) scenario involving a dual satellite configuration in which the principal measurements are the relative range-rates between the satellites. In the initial simulations, a geopotential model complete through degree and order 180 was used (Schutz et al., 1987). The GRM simulation was extended to include a geopotential model complete through degree and order 360 (Schutz et al., 1988). The satellites in the GRM scenario were assumed to be in 'frozen', polar orbits with a mean altitude of 160 km and a repeat ground track period of 32 sidereal days. For these simulations the earth was assumed to have a constant angular velocity and a static geopotential.

To create as accurate an ephemeris as resources would permit, the equations of motion were solved numerically using Encke's formulation and a class II, fixed mesh multistep algorithm of order 10. The simulations were carried out on the CRAY X-MP/24 computer at the University of Texas using single precision arithmetic which represents floating point numbers using a 48 bit mantissa and a 16 bit exponent. The first simulation (S8705) was carried out using an integration stepsize of five seconds and required 5.6 hours of CPU time. The second simulation (S8703) was carried out using an integration stepsize of four seconds and required 19.2 hours of CPU time. The nearly four fold increase in CPU time reflects the increase in the size of the geopotential model from degree and order 180 to 360. In both simulations the ground track closed to within two kilometers after 32 sidereal days (White, 1987).

In addition to creating these simulations, special studies were carried out on the effects of solid and ocean tides, luni-solar and planetary gravitational forces, and the mass distributions caused by ocean eddies (McNamee, 1986) on the relative range-rate measurements. A study of the disturbance compensation system (DISCOS) was also carried out to verify the proposed control law and estimates of fuel consumption (Antreasian, 1988).

Simulation of a Gradiometer Mission

The products of the GRM simulation have been used to simulate the orbital gradiometer mission. The orbit for the gradiometer mission is assumed to have the same characteristics as GRM, i.e, a polar, frozen orbit with a mean altitude of 160 km and a repeat ground track period of 32 sidereal days. The ephemeris computed for the lead satellite of simulation S8703 is taken to be the true ephemeris for the gradiometer mission. The true gradiometer measurements are simulated by the gravity gradient tensor which is computed using the true ephemeris and a geopotential complete to degree and order 360. The measurement interval is taken to be the same as the ephemeris interval, i.e., four seconds.

Analysis of a Simulated Gradiometer Mission

The simulated true ephemeris and gradiometer measurements can be used to study the orbit determination requirements of the mission, i.e., the effects of orbit uncertainties on the solution for the geopotential parameters, and to study various techniques for recovering the geopotential parameters using gradiometer measurements. The simulation also provides a common data set for the evaluation of results from different researchers and a basis for comparison of gravity gradient computations.

Various tracking systems may be considered for this mission including GPS, satellite laser ranging, PRARE, DORIS, or other suitable systems. Since some form of global tracking will be required for the mission, GPS will probably be part of the overall tracking system (Yunck et al., 1986). Whichever tracking system is used, there are two possible approaches that can be used to determine the orbit of the satellite and recover the geopotential parameters. The first, or gradiometer, approach uses only the tracking system information to establish a nominal orbit for the mission and, once the nominal orbit is computed, uses the gradiometer measurements to recover the geopotential parameters. The second, or dynamical, approach involves using the tracking data along with the gradiometer measurements to determine the orbit and recover the geopotential coefficients simultaneously. The fundamental difference between these two approaches is that the first approach is similar to creating a gravity surface by adjusting the geopotential parameters while the second approach is dependent on the orbit perturbation frequency spectrum including the amplified effects due to resonance.

To illustrate the gradiometer approach, a simulation was carried out in which the observations were the gradiometer measurements computed along the true orbit using only the geopotential coefficients from degree and order 10 through degree and order 15. The gradiometer measurements were used with a least squares algorithm in attempt to recover the geopotential coefficients for arc lengths of up to 60 hours. To represent the effect of orbit uncertainties on the solution, the partial derivatives of the observations with respect to the coefficients were evaluated along a nominal orbit which is randomly perturbed in the radial direction from the true orbit. The accuracy of the solution for the coefficients is evaluated by computing the absolute value of the normalized differences between the estimated coefficients and the true coefficients, i.e.,

$$\delta C = \frac{C_{TRUE} - C_{ESTIMATED}}{C_{TRUE}}$$

Figure 1 shows the results for the solution of $C_{14,12}$ which is typical of all the solutions. The effects of radial orbit uncertainties (1σ) of 0 cm, 5 cm, 30 cm, and 50 cm are represented in

Figure 1. For the case of no orbit error, nine to ten significant figures of $C_{14,12}$ are recovered. For the case of 50 cm radial uncertainty, six to seven significant digits are recovered. This is a very limited example since the solution involved a relatively small number of coefficients and a relatively low degree and order coefficient.

To illustrate the dynamical approach, nominal orbits were determined using the entire 32 day, true ephemeris (S8703) as simulated tracking data and the Goddard Earth Model 10B (GEM-10B) as the *a priori* gravity model while solving for selected resonance coefficients. The selected resonance coefficients were the first two pairs (C_{nm} and S_{nm}) of orders 33, 49, and 82. The results of these solutions are given in Table 1. The results indicate that the resonance terms will have amplified effects in the dynamical solution for the gravity field.

Future Research

Future research of the orbital gradiometer mission includes studies of the gradiometer or dynamical approaches to determine the orbit of the satellite and recover the geopotential parameters, studies of the effects of various error sources on the solutions including tidal errors, nontidal ocean phenomena, and spacecraft attitude errors, and to investigate the adequacy of a six month mission.

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Table 1 Resonant Effects on the Orbit Residuals			
RMS (meters)	with order 82*	with orders 33,82*	with orders 33,49,82*
radial	64.9	60.4	58.1
transverse	619.5	180.3	148.6
normal	31.8	21.7	33.8

* after small adjustments in position vector

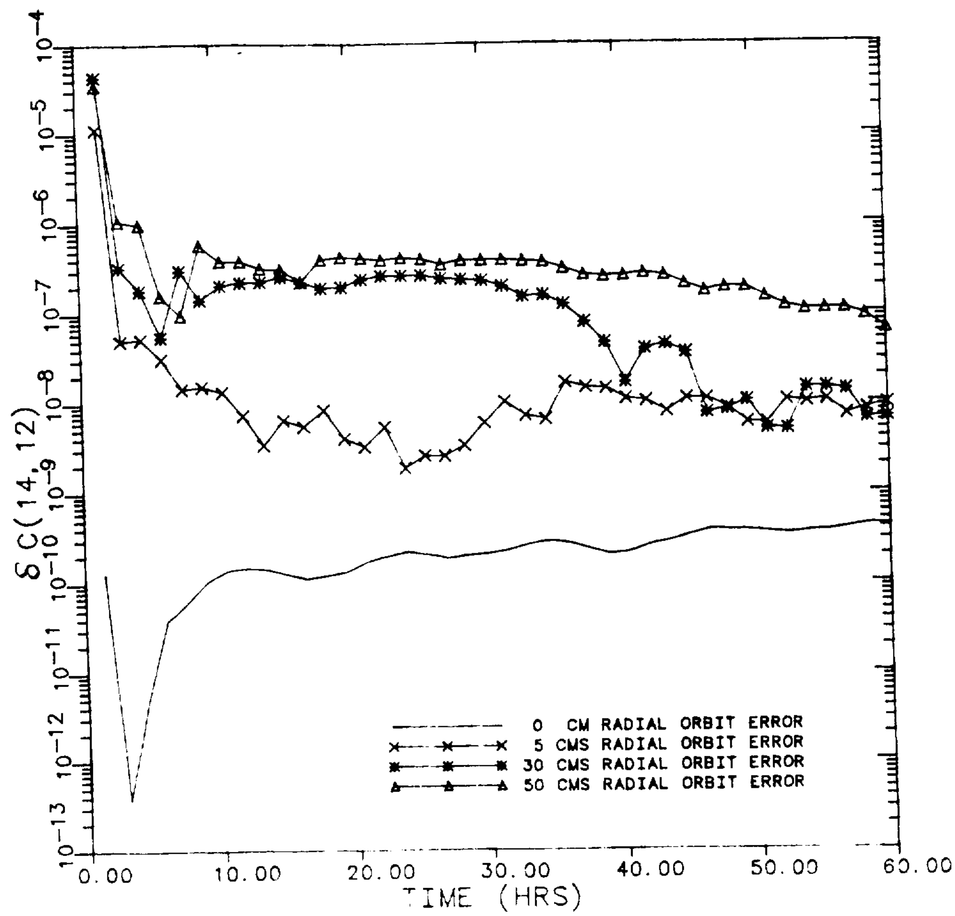

Figure 1

Normalized errors in the solution for $C_{14,12}$ as a function of radial orbit uncertainty and orbital arc length

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